Benefits of Stormwater Management: Heat Island Reduction

Contents

Overview

Since about 1940, temperatures in urban areas have increased by about 0.5-3.0 degrees C. Typically, electricity demand in cities increases by 2-4% for each 1 degree C increase in temperature (Akbari 2001). In the US, the increase in air temperature due to heat island effect is responsible for 5-10% of urban peak electric demand for air conditioning use, and as much as 20% of population-weighted smog concentrations in urban areas (Akbari 2001).

The primary techniques evaluated for this summary include shade tree planting, the use of reflective (or high albedo) surfaces, the use of permeable pavements, and the use of vegetative roofs. Shade trees can (Akbari 2001). Green (vegetative) roofs help cool buildings by providing shade, increasing evapotranspiration, and increase roof albedo.

The following are summaries of individual research and policy studies that monetize, quantify, or describe urban heat island mitigation strategies. Some information is also given about considerations when developing programs to implement such strategies.

Supporting Research

Monetized Benefits

Valuing the benefits of shade trees, Los Angeles, CA. Akbari 2002

- Over the life of a tree, cost savings from benefits can be up to $200. Cost savings depend on how much is spent on planting and maintaining trees, which can vary from $10 to $500 per tree.

- Final conclusions suggest annual benefits of $270M for LA after 15-20 years of planting trees.
- Authors review existing studies and performed some independent data analysis.

Evaluating the savings potential and air quality benefits of UHI mitigation strategies, Los Angeles, CA. Akbari 2005

- Author estimates that cooling energy savings in the US from cool surfaces and shade trees, when fully implemented, is about $5 billion per year (assuming $100 per air-conditioned house). These benefits come from reduced need for cooling due to overall reduced temperatures.
- Mesoscale meteorological and photochemical models (CSUMM, MM5, UAM) were used to understand the impact of large-scale increases in albedo and vegetation on urban climate and ozone air quality.
- Figure 1 shows the overall methodology used to evaluate the direct and indirect effects of heat-island mitigation measures on energy use and urban air pollution (Akbari 2005).

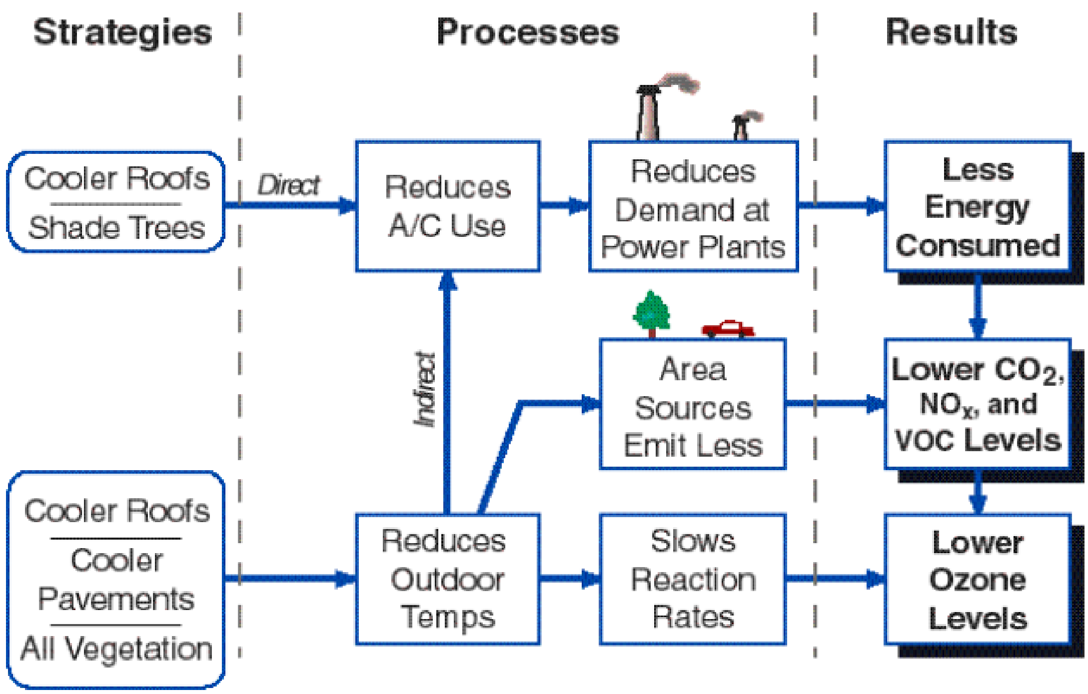

Figure 1 Methodology for energy and air quality

Impact of trees and white surfaces on residential heating and cooling energy use, Canada. Akbari and Taha, 1992

- Authors used parametric computer simulations of microclimates and energy performance of prototypical houses to evaluate the use of vegetation and high-albedo materials to modify the urban microclimate.
- Study was conducted for the cities of Toronto, Edmonton, Montreal, and Vancouver, Canada.
- Authors estimate annual savings in heating and cooling costs for different houses ranging from $30 to $180 in urban areas and from $60 to $400 in rural zones.

Using cool surfaces and shade trees to reduce energy use and improve air quality, Los Angeles, CA. Akbari et al 2001

- Mitigation of urban heat islands can potentially reduce national energy use in air conditioning by 20% and save over $10B per year in energy use and improvement in urban air quality.

Benefits of street and park trees in 5 US cities, US. McPherson et al. 2005.

- Case studies of five US cities (Fort Collins, Colorado; Cheyenne, Wyoming; Bismark, North Dakota; Berkeley, California; and Glendale, Arizona) describing the structure, function, and value of street and park tree populations.
- Cities spent $13-65 annually per tree but benefits ranged from $31 to $89 per tree.
- Per every dollar invested in management, benefits returned annually ranged from $1.37 to $3.09.
- Results from these five cities cannot be generalized to other cities because variability among cities is high.

Strategies for heat island mitigation and smog reduction, Los Angeles, CA. Rosenfeld et al. 1997.

- In the target city of Los Angeles, annual residential air-conditioning (A/C) bills can be reduced directly by about US$100 M and, because these strategies serve to cool the air in the Los Angeles basin and reduce smog exceedance levels by about 10%, an additional savings of US$70 M in indirect cooling and US$360 M in smog-reduction benefits – a total savings of about US$1/2 B per year – is possible.
- Trees are most effective if they shade buildings, but the savings are significant even if they merely cool the air by evapotranspiration.
- In Los Angeles, avoided peak power for air conditioning can reach about 1.5 GW (more than 15% of the city's air conditioning).
- Generalized to the entire US, the authors estimate that 25 GW can be avoided with potential annual benefits of about US$5 B by the year 2015.
- Authors caution that, in some climates, switching from a dark-colored roof to a white or light-colored roof, and/or adding shade trees, may result in a heating penalty in winter.
- Methods:
    - DOE-2 program used to estimate direct savings from installing cool roofs and planting shade trees by simulating two inland prototype houses
    - Used Taha's meteorological model to estimate indirect energy savings

- Analysis indicates that LA heat island could be reduced by as much as 3 degrees C. Cooler roof and paving surfaces and 11 M more shade trees could reduce ozone exceedance by 12% in Los Angeles and by slightly less in other smoggy cities. This 12% improvement exceeds that estimated for cleaner-burning gasoline and dramatically exceeds estimates for reductions from electric or hybrid vehicles.

The Potential for Reducing Urban Air Temperatures and Energy Consumption Through Vegetative Cooling, Southern California. Kurn et al. 1994

- Authors used a network of 23 weather stations to conduct transverse measurements of temperature and humidity in the Whittier Narrows Recreation Area in Los Angeles County
- Near-surface air temperatures over vegetated areas were 1-2 degrees C lower than background air temperatures.
- Authors estimate that vegetation may lower urban temperatures by 1 degree C, while the establishment of vegetative canopies may lower local temperatures by an additional 2 degrees C. An increase in vegetation in residential neighborhoods may reduce peak loads in the Los Angeles area by 0.3 GW, and reduce energy consumption by 0.2 BkWh/year, saving $20 million annually. Large additional savings would result from regional cooling.

Chicago Urban Forest Climate Project, Chicago, IL. McPherson et al. 1994

- There are an estimated 50.8 million trees in the Chicago area of Cook and DuPage Counties.
- Shade, lower summer air temperatures, and a reduction in wind speed associated with increasing tree cover by 10 percent can lower total heating and cooling energy use by 5 to 10 percent annually ($50 to $90 per dwelling unit).
- The projected net present value of investment in planting and care of 95,000 trees in Chicago is $38 million ($402 per planted tree), indicating that the long-term benefits of trees are more than twice their costs.

Triple Bottom Line Assessment of Traditional and Green Infrastructure Options. Philadelphia, PA. Raucher 2009.

- Green infrastructure (trees, green roofs, and bio-retention areas) – such as would be implemented under the LID-oriented options − creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air and reduce the urban heat island (UHI) effect. This cooling effect will be sufficient to actually reduce heat stress-related fatalities in the City during extreme heat wave events.
- Authors estimate that city-wide, 196 premature fatalities could be avoided over the 40-year project planning horizon for the 50% LID option. This corresponds to a savings of nearly $1.1 billion (value of statistical life estimates). This estimate does not include the avoided medical costs and reduced suffering of morbidity impacts (i.e., the costs associated with those individuals who would otherwise suffer adversity from heat stress, but would not be projected to die from the impact).

Case Studies

Evaluating the savings potential and air quality benefits of UHI mitigation strategies, Los Angeles, CA. Akbari 2005

- Authors primarily evaluate the benefits of reflective surfaces and planting of urban vegetation.
- Author estimates that resurfacing ~2/3 of the pavements and rooftops with reflective surfaces and planting three trees per house can cool down LA by an average of 2-3K.
- Corresponding reductions in urban smog exposure would be roughly equal to removing the basin entire on-road vehicle exhaust.
- Mesoscale meteorological and photochemical models (CSUMM, MM5, UAM) were used to understand the impact of large-scale increases in albedo and vegetation on urban climate and ozone air quality.

Impact of trees and white surfaces on residential heating and cooling energy use, Canada. Akbari and Taha, 1992

- Authors used parametric computer simulations of microclimates and energy performance of prototypical houses to evaluate the use of vegetation and high-albedo materials to modify the urban microclimate.
- Study was conducted for the cities of Toronto, Edmonton, Montreal, and Vancouver, Canada.
- Simulations indicated that by increasing the vegetative cover of the neighborhood by 30% (corresponding to approximately three trees per house) and increasing the albedo of the houses by 20% (from moderate-dark to medium-light color) can have the following effect:
    - The heating energy in Toronto can be reduced by about 10% in urban houses and 20% in rural houses.
    - The cooling energy can be reduced by 40 and 30%, respectively.
    - In urban houses of Edmonton, Montreal, and Vancouver, savings in heating energy use were about 10%. Cooling energy can be totally offset in Edmonton and Vancouver, and average savings of 35% can be achieved in Montreal.

Using cool surfaces and shade trees to reduce energy use and improve air quality, Los Angeles, CA. Akbari et al 2001

- Since ~1940, temperatures in urban areas have increased by about 0.5-3.0 degrees C. Typically, electricity demand in cities increases by 2-4% for each 1 degree C increase in temperature.
- Authors estimate that 5-10% of the current urban electricity demand is spent to cool buildings just to compensate for the increased 0.5-2.0 degree C in urban temperatures.
- Mitigation of urban heat islands can potentially reduce national energy use in air conditioning by 20% and save over $10B per year in energy use and improvement in urban air quality.
- Implementation of cool roofs and cool pavements may increase the life expectancy of both, due to reduced stresses on materials.

Urban forestry, living roofs, and light surfaces to mitigate UHI in New York City, New York, NY. Rosenzweig et al. 2006

- Methods:
  - Use of regional climate model (MM5) in combination with observed meteorological, satellite, and GIS data to determine the impact of urban forestry, living (green) roofs, and light-colored surfaces on near-surface air temperature and the urban heat island in New York City.
  - Nine mitigation scenarios are evaluated city-wide and in six case study areas.
- Results:
  - All of the mitigation strategies have a significant temperature impact (mitigation scenarios evaluated include urban forestry, light surfaces, living roofs, ecological infrastructure, urban forestry + light roofs and a combination of all strategies)
  - A combined strategy that maximizes the amount of vegetation in New York City by planting trees along streets and in open spaces, as well as by building living (or green) roofs, offers more potential cooling than any individual strategy.
  - Among the single-strategy scenarios, light surfaces, light roofs, and living roofs can potentially reduce the summer peak electric load more than the other strategies. At 50% redevelopment of available area, light surfaces can potentially reduce peak load by 0.51%, light roofs by 0.37%, and living roofs by 0.36%. Given cost and benefit assumptions, the cost per MW reduction ranges from $8.4M for light surfaces to $154M for living roofs.
  - Cost per 0.1 degree F temperature reduction differed between the six case study areas.

Mitigation of heat island effect in New Jersey, New Jersey. Solecki et al. 2005

- Authors used CITYgreen, a GIS-based modeling application, to estimate the potential benefits of urban vegetation and reflective roofs as HUI mitigation strategies for six case study sites in and around Newark and Camden, New Jersey.
- Implementation of urban heat island (UHI) mitigation strategies such as increased vegetative cover, and higher-albedo surface materials can reduce the impacts of biophysical hazards in cities, including heat stress related to elevated temperatures, air pollution and associated public health effects.
- Analysis showed that urban vegetation can reduce health hazards associated with the UHI effect by removing pollutants from the air.
- Less affluent, inner-city neighborhoods are the ones in which the hazard potential of the UHI effect is shown to be greatest. However, these neighborhoods have less available open space for tree planting and therefore a lower maximum potential benefit.
- Results show that urban vegetation is an effective and economically efficient way to reduce energy consumption and costs at the sites.

Urban forests in Beijing, China. Yang et al. 2005

- Study examines the proposal by the municipal government to plant trees as a measure to alleviate air pollution in Beijing.
- Results show that there are 2.4 million trees in the central part of Beijing.
- Trees in the central part of Beijing removed 1261.4 tons of pollutants from the air in 2002. The air pollutant that was most reduced was PM_{10}, with a reduction that amounted to 772 tons.
- The carbon dioxide (CO_2) stored in biomass form by the urban forest amounted to about 0.2 million tons.
- Method used in the study to determine different urban cover types involved an estimation of the area of the types on satellite image and a field survey conducted to measure structural parameters of the Beijing urban forest.

Examination of land-based benefits of stormwater best management practices, US. Abt 2010

- Authors used the heat island Mitigation Impact Screening Tool (MIST) to evaluate the range of potential impacts due to increases in the percentage of city-wide vegetative cover. Screening calculations were performed for 10 cities (Washington, D.C.; Philadelphia, PA; Louisville, KY; Detroit, MI; Baton Rouge, LA; Dallas, TX; Phoenix, AZ; Los Angeles, CA; Sacramento, CA; and Atlanta, GA) specifying increases in city-wide vegetative cover ranging from 0% to 25%.
- On average, increasing city-wide vegetative cover by 5% resulted in an average reduction of about 0.4 F for the ten cities and about a 0.5% reduction in residential electricity usage. It should be noted that the use of percentages may be misleading for some cities.
- These reductions in temperature may have an effect on human health. Further study is required.

General benefits of UHI mitigation strategies

Benefits of the urban forests, US. Dwyer et al. 1992

- Urban trees and forests can provide benefits including a more pleasant, healthful, and comfortable environment to live, work, and play in; savings in the costs of providing a wide range of urban services; and substantial improvements in individual and community well-being.
- Paper cites many secondary sources, many of which we examine elsewhere.
- Physical/biological environment and process benefits listed include:
    - Energy and carbon dioxide conservation (reduce cost of heating and cooling buildings)
    - Improved air quality
    - Reduction in rate and volume of stormwater runoff, flooding damage, stormwater treatment costs, and water quality problems
    - Noise reduction
    - Promotion of ecological stability by providing habitat for wildlife, conserving soil, and enhancing biodiversity.
- Social dimensions affected include:
    - Increase in desirable environments
    - Reduced stress and improved physical health for urban residents

- Improved real estate values
- Psychological benefits
- Local economic development
- Improved sense of community

Considerations when Developing Mitigation Strategies for UHI

- The two primary factors to be considered in designing a large-scale urban tree program is the potential room (space available) for planting trees, and the types of programs that utilize and employ the wide participation of the population (Akbari 2002).
- The albedo of a city may be increased at minimal cost if high-albedo surfaces are chosen to replace darker materials during routine maintenance of roofs and roads. Incentive programs, product labeling, and standards could promote the use of high-albedo materials for buildings and roads. Similar incentive-based programs need to be developed for urban trees (Akbari 2001).

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